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THE EFFECT OF XYLIDINES ON THE LOAD-CARRYING CAPACITY OF AN AIRCRAFT-ENGINE OIL - I

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MEMORANDUM REPORT

THE EFFECT OF XYLIDINES ON THE LOAD-CARRYING CAPACITY OF AN AIRCRAFT-ENGINE OIL - I

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SUMMARY

Tests were made to determine the effect of xylidines on the load-carrying capacity of aircraft-engine oil in several test devices. As part of an investigation on the suitability of xylidines as an anti-knock component in aviation gasoline, Navy 1120 lubricating oil and Navy 1120 lubricating oil to which had been added 2 percent by weight of commercial mixed xylidines were tested in a Shell four-ball machine, an Almen machine, an SAE extreme-pressure lubricant-testing machine, and in an NACA bearing-testing attachment.

Results of the tests are summarized as follows:

	Navy 1120 oil	Navy 1120 oil plus 2-percent xylidines	Percentage change with xylidines
Four-ball machine:			
Time for 360 rpm deceleration, min	2.220 ±0.011	2.147 ±0.019	-3.3
Coefficient of sliding friction at contact surfaces. .	0.1109 ±0.0006	0.1147 ±0.0010	+3.4
Almen machine:			
Failure load, lb/sq in. . .	4100 ±580	3500 ±370	-15
Coefficient of friction (all loads)	0.17 ±0.01	0.23 ±0.01	+35
Wear-scar width, in.	0.049 ±0.010	0.066 ±0.021	+35
SAE machine:			
Scoring load, lb	138 ±12	106 ±4	-23
NACA attachment:			
Failure load, lb/sq in. series 1 . . .	3160 ±7	3000 ±17	-5.1
series 2 . . .	2985 ±24	2920 ±9	-2.2

Addition of 2 percent by weight of xylidines decreased the load-carrying ability of Navy 1120 lubricating oil on the machines tested. Because these machines do not reproduce aircraft-engine operating conditions, these results should be considered as indicating a difficulty to be watched for rather than a difficulty to be expected. It is also pointed out that the percentage of xylidines in the oil tested was higher than might be experienced in service.

INTRODUCTION

At the request of the Army Air Forces, an investigation was conducted on the suitability of xylidines as an antiknock component in aviation gasolines. The work coyered by this report presents the effect of xylidines on the load-carrying capacity of aircraft-engine oil. Such tests were advisable because the fuel will inevitably contaminate the lubricant, either through blow-by or through the practice of oil dilution with fuel during cold-weather operation. Specifically, Navy 1120 lubricating oil and Navy 1120 lubricating oil to which had been added 2 percent by weight of a commercial xylidine mixture were tested in four test devices.

The tests were conducted at the Aircraft Engine Research Laboratory, National Advisory Committee for Aeronautics, Cleveland, Ohio, during July 1943.

TYPES OF OIL

Navy 1120 lubricating oil was used alone and also Navy 1120 lubricating oil containing 2 percent by weight of a commercial xylidine mixture. These two oils were tested in a Shell four-ball machine, an Almen machine, an SAE extreme-pressure lubricant-testing machine, and an NACA bearing-testing attachment.

THE SHELL FOUR-BALL MACHINE

Apparatus and test procedure. - The four-ball machine is described in references 1 and 2. Three half-inch steel bearing balls are clamped together in a cup that holds the lubricant to be tested. A fourth ball, which rests on them (fig. 1) is fixed in a steel wheel of large moment of inertia about its vertical axis. When the upper member is caused to spin, the top ball rubs against the other three. From the observed rate of deceleration of the top, its weight, and its moment of inertia, the value of the coefficient of sliding friction at the contact point of the upper and a lower ball can be calculated and is taken as a measure of the lubricating properties of the oil.

The rate of deceleration was determined by timing the interval that elapsed while the top was slowing down from 720 to 360 rpm. These two speeds were observed with a stroboscope flashing at the constant rate of 720 times per minute. Other studies have shown that the deceleration is essentially constant with respect to time.

The tests were made according to the following plan: Five runs were made with Navy 1120 oil, and five runs with Navy 1120 oil containing 2 percent by weight of xylidines. The balls were then thoroughly rinsed in toluene and ether. Five runs were then made with Navy 1120 oil, and three with the oil containing xylidines. The balls were not changed during the entire series of tests.

Results and discussion. - The results of the tests are shown in the following table:

	Time for 360 rpm deceleration (min)		Coefficient of sliding friction at contact surfaces	
	Navy 1120 oil	Navy 1120 oil plus 2-percent xylidines	Navy 1120 oil	Navy 1120 oil plus 2-percent xylidines
Test 1	2.217 ±0.010	2.149 ±0.017	0.1110	0.1145
Test 2	2.223 ±0.011	2.142 ±0.021	.1107	.1148
Average	2.220 ±0.011	2.147 ±0.019	.1109 ±0.0006	.1147 ±0.0010

The addition of 2 percent by weight of xylidines to the oil raised the coefficient of friction in the four-ball test by 3.4 percent. It is to be noticed that the effect observed was five times the mean probable error and therefore considerably outside the range of experimental uncertainty.

The weight of the top used was 30.75 pounds. The extent of the contact area of a ball was estimated by Herz's theoretical formula as given in reference 3:

$$a = 1.109 \sqrt[3]{\frac{PR}{2E}}$$

where

a radius of contact area

P load perpendicular to contact face

R radius of balls

E modulus of elasticity

It was found that a pressure of about 234,000 pounds per square inch prevailed at the contact surfaces. As expected, therefore, the values of the coefficient of friction were high compared with values usually encountered. The oils were tested in the boundary region of lubrication where the viscosity of the lubricant is without measurable effect on the coefficient of sliding friction, as has been shown in unpublished tests with the four-ball machine at this laboratory.

THE ALMEN MACHINE

Apparatus and test procedure. - The Almen machine for measuring load-carrying ability is described in reference 4. The machine provides a 1/4-inch drill-rod journal rotated at constant speed in a split bushing of SAE 2315 cold-drawn steel (fig. 1). This bearing assembly is immersed in the test oil and the journal is brought to the test speed. At regular intervals the load on the split bushing is increased in increments of 1000 pounds per square inch based on the projected bearing area. The torque exerted on the bushing through friction is indicated by means of a hydraulic system. The load at which bearing seizure occurs is recorded as the failure load. The bearing and journal were cleaned by treatment with petroleum naptha in a Soxhlet extractor.

Five runs were made using Navy 1120 oil, then ten runs using Navy 1120 oil containing 2 percent by weight of xylidines, and then five runs with Navy 1120 oil. All tests were made at a journal speed of 600 rpm, ambient-oil temperature, and with 1000 pounds per square inch added every 50 journal revolutions until failure load was reached. The journal was stopped immediately at failure. The width of the wear scar was measured at four equally separated locations around each test journal.

Results and discussion. - The Almen test results and their probable errors were as follows:

	Navy 1120 oil	Navy 1120 oil plus 2-percent xylidines
Average failure load, lb/sq in. . . .	4100 ±580	3500 ±370
Coefficient of sliding friction at 1000 lb/sq in.	0.17	0.23
Average coefficient of friction, all loads	0.17 ±0.01	0.23 ±0.01
Average width of wear scar, in. . . .	0.049 ±0.010	0.066 ±0.021

In the Almen test the effect of xylidines added to Navy 1120 oil was to decrease the failure load by about 15 percent, increase the coefficient of friction by about 35 percent, and increase the wear-scar width by about 35 percent. Because the observed coefficients of friction were 100 times those generally experienced with hydrodynamic lubrication, boundary conditions of lubrication apparently existed during the tests. The observed effects were thus independent of the decrease in oil viscosity caused by adding xylidines. (See table I.)

THE SAE EXTREME-PRESSURE LUBRICANT-TESTING MACHINE

Apparatus and test procedure. - In reference 5 are given the description, the installation, and the directions for operation of the SAE extreme-pressure lubricant-testing machine. In this device two cylindrical steel test specimens (Timken Test Cups T-48651) are rotated in line contact with each other and in opposite directions, with provision for controlling the speed of rotation, the slipping velocity, and the rate of applying pressure at the line contact between the rotating cylinders (fig. 1). The lower specimen rotates in the test oil. The scale reading of load at which scoring of the test cups first occurs is recorded as a measure of the extreme-pressure lubricating quality of the oil.

Before each test, the test cups were cleaned by washing twice with kerosene, boiling in ethyl alcohol, and heating to 110° C at 4 millimeters pressure for 2 hours. They were immediately transferred to a sample of the test oil.

Ten runs were made for both Navy 1120 oil and for Navy 1120 oil containing 2 percent by weight of xylidines under the following conditions:

Main shaft speed, rpm	500
Rubbing ratio	1:14.6
Run-in at 30-pound load, seconds	30
Rate of load, pounds per minute	460

The unscored regions of the surfaces of certain test cups that gave values of failure load either higher than average or lower than average for the same oil were examined both axially and circumferentially with a Brush surface analyzer to ascertain whether variations in surface finish would account for observed differences among the load data.

Results and discussion. - The average scoring loads and their probable error in the SAE machine tests were as follows:

	Scale reading (lb)
Navy 1120 oil	138 ±12
Navy 1120 oil plus 2-percent xylidines	106 ±4

The effect of xylidines was to decrease the load-carrying ability of the Navy 1120 oil in these tests by about 23 percent. That this effect of added xylidines was well outside experimental error is shown by the fact that the difference between the scoring loads for the two oils was four times the mean probable error for the observed loads. Inasmuch as the test specimens made line contact, the bearing pressures were of such magnitude that boundary conditions prevailed and the load carried was independent of the change in viscosity of the oil caused by the xylidines. (See table I.)

It was evident from the surface-analyzer data that differences in the load carried for the same oil were not directly accountable in terms of surface-finish variations.

THE NACA BEARING-TESTING ATTACHMENT

Apparatus and test procedure. - The device used in the bearing tests was a preliminary version of a machine being used at AERL with a Tinius-Olsen tensile-testing machine. A sketch is shown in figure 2. The tensile machine is used to apply the load on a $1\frac{3}{16}$- by $1\frac{3}{16}$-inch SAE 64 bronze bearing against a hardened steel shaft rotated by an electric motor at 1700 rpm. The clearance-diameter ratio of the bearing used in all tests was about 0.003. A gear pump supplies oil to the bearing through a 1/8-inch hole in the rotating shaft.

Load was applied to the bearing supplied with Navy 1120 oil, at a constant rate of 6000 pounds per minute. As the friction increased in the hydrodynamic region of lubrication, the current supplied to the driving motor, as measured by an ammeter, slowly increased. At a load that was easily recognizable for each run, the ammeter needle swung toward higher currents at a rapid rate. As soon as this result occurred, the loading valve on the tensile-testing machine was closed, releasing the load on the bearings and the maximum load was recorded. Direct measurement of the torque on the test bearing showed that the jump in motor current corresponded to lubrication failure.

Several successive determinations of the failure load were made in this manner for the Navy 1120 oil. Then, without stopping the machine, xylidines to make up 2 percent by weight were stirred into the test oil and several successive determinations of the failure load were again made. After these tests were completed, the bearing-testing attachment was completely flushed with kerosene and Navy 1120 oil and the tests were repeated (series 2). The same bearing was used in all the tests.

Results and discussion. - Figure 3 shows the results of the two series of tests. The failure load for the bearing showed a tendency to increase as the bearing wore in. In both series of tests the load-carrying capacity was sharply lessened by averages of 5.1 percent and 2.2 percent, respectively, when the 2-percent xylidines were added to the oil as shown in the following table:

	Average failure load (lb/sq in. of projected area)	
	Navy 1120 oil	Navy 1120 oil plus 2-percent xylidines
Series 1	3160 ±7	3000 ±17
Series 2	2985 ±24	2920 ±9

CONCLUDING REMARKS

In all experiments the effect of the addition of 2 percent by weight of xylidines was to make Navy 1120 oil a poorer lubricant in the boundary region of lubrication, where metal-to-metal contact occurs.

The explanation of this phenomenon must await further investigation. It seems possible that the presence of xylidines, by inhibiting oxidation of the oil at the rubbing surfaces, prevents the formation of compounds that are beneficial in lowering the friction. In the Almen and the SAE machines, which afford opportunity for the air to come in good contact with the oil at the rubbing surfaces, the observed effect of the xylidines was greater than for the four-ball machine and the NACA bearing-testing attachment.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 2, 1943.

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TABLE I. - EFFECT OF XYLIDINES ON VISCOSITY OF NAVY 1120 OIL
[Conversion of viscosity in centistokes to viscosity in Saybolt seconds by A.S.T.M. designation D 446-39; viscosity index by A.S.T.M. designation D 567-40 T]

Temperature (°F)	Viscosity			
	Navy 1120 oil		Navy 1120 oil plus 2-percent xylidines	
	Kinematic viscosity (centistokes)	Saybolt universal viscosity (sec)	Kinematic viscosity (centistokes)	Saybolt universal viscosity (sec)
100	392.3	1812	313.6	1449
130	151.1	700	124.6	576
175	49.0	228	41.5	193
210	25.63	119.2	22.46	104.5
Viscosity index	95		98	

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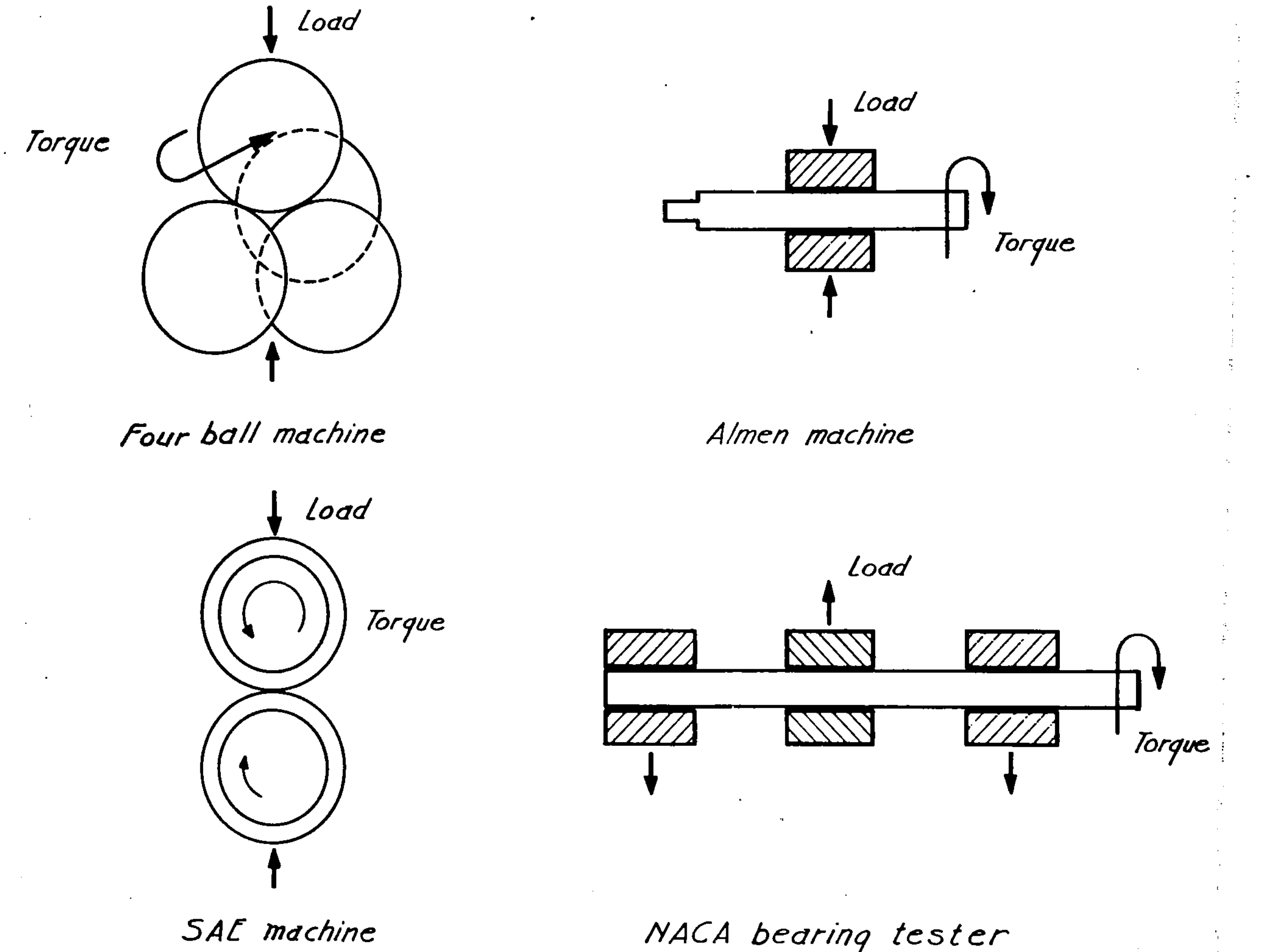
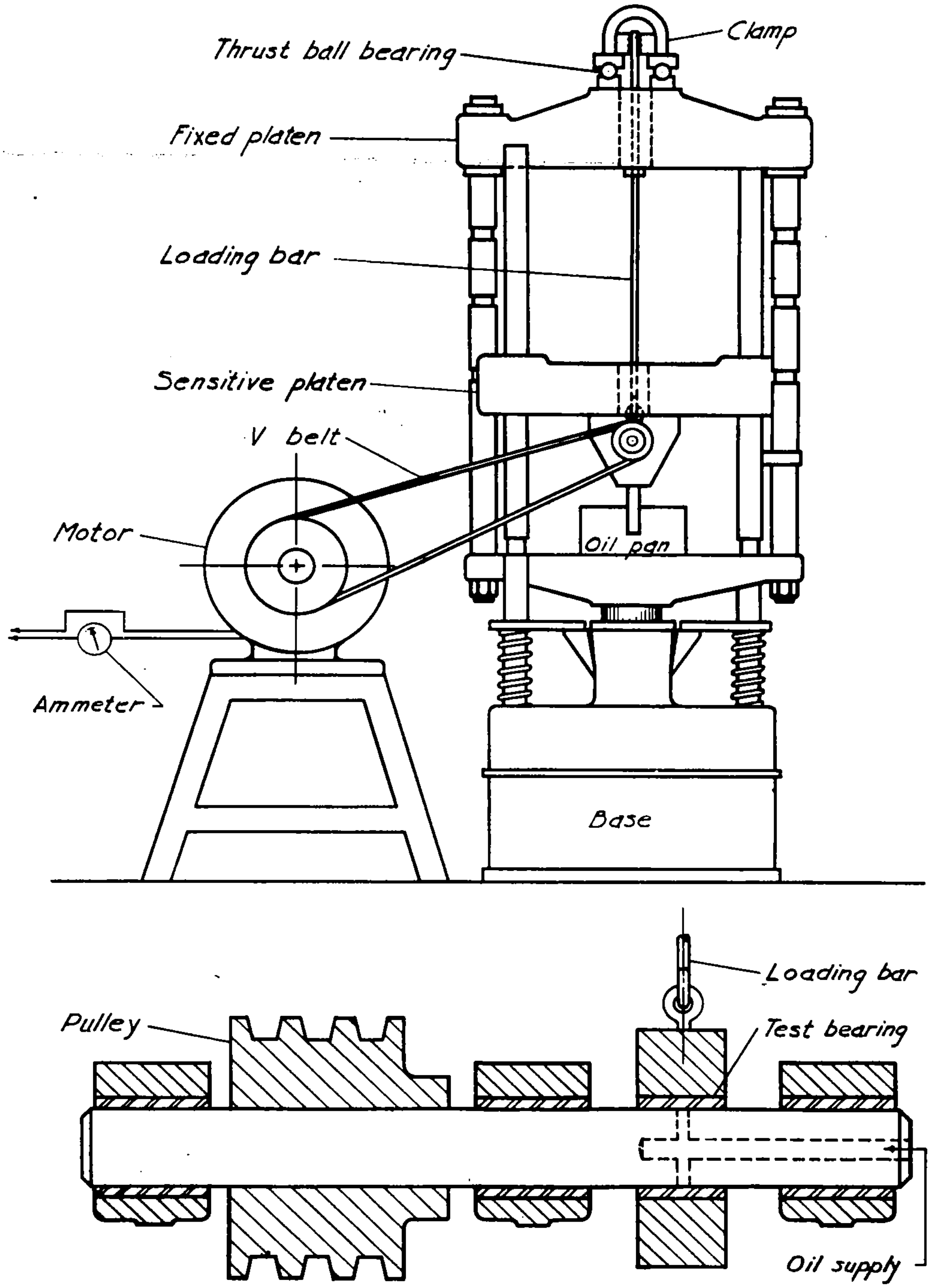


Figure 1.- Diagrammatic sketch illustrating principle of load-carrying-capacity test machines.



Detail of test journal

Figure 2-NACA bearing-testing attachment for tensile test machine.

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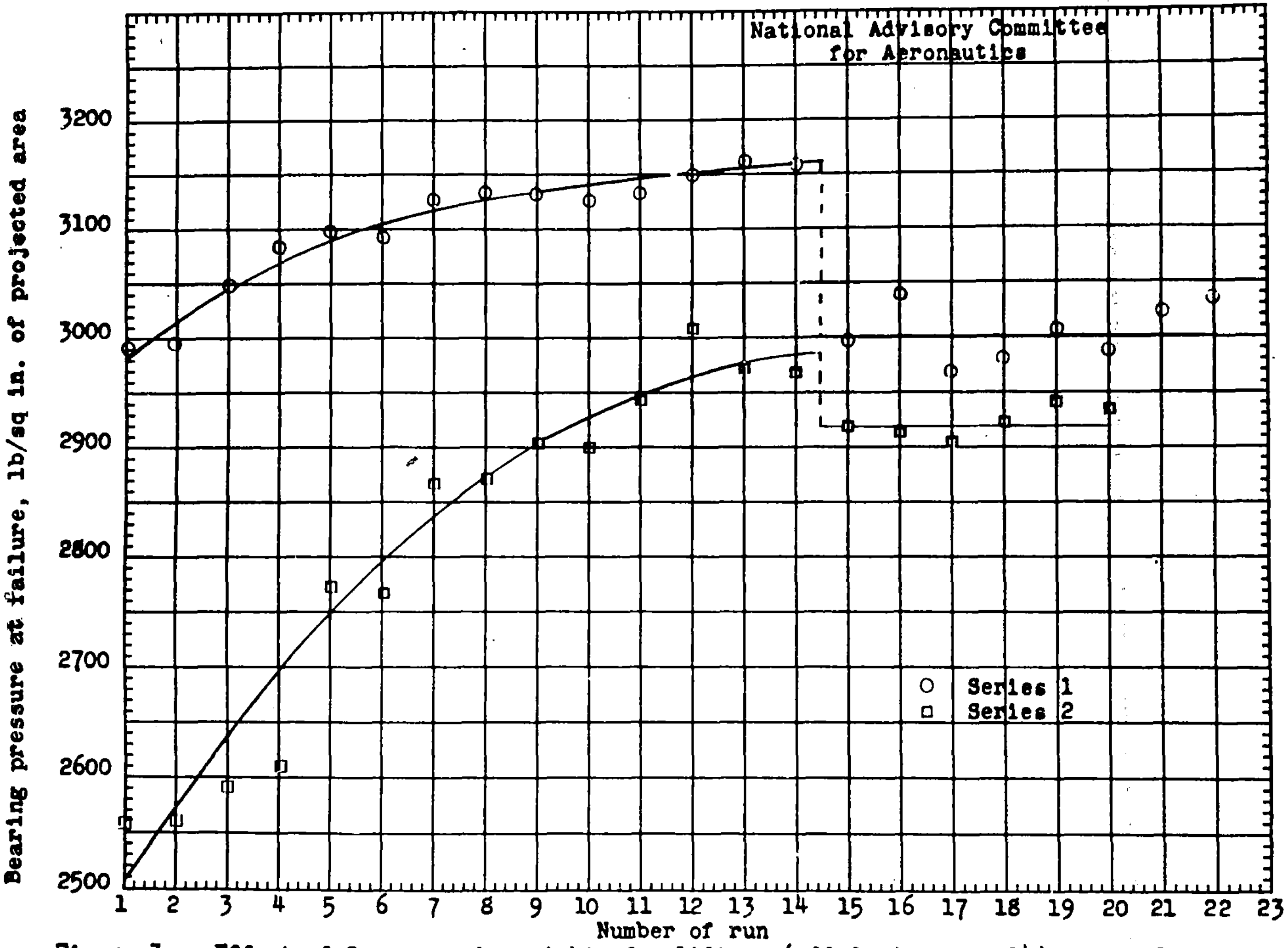

Figure 3. - Effect of 2 percent by weight of xylidines (added after run 14) on the load-carrying capacity of Navy 1120 oil in a 1 3/16- by 1 3/16-inch bronze bearing. NACA bearing-testing attachment; oil-in temperature: series 1, 134° F; series 2, 150° F; oil pressure: series 1, 19 pounds per square inch; series 2, 25 pounds per square inch; loading speed, 6000 pounds per minute; speed, 1700 rpm.